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METHODS OF CALCULATING THE STRENGTH AND MODULUS OF ELASTICITY OF PLYWOOD IN COMPRESSION

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METHODS OF CALCULATING THE STRENGTH AND
MODULUS OF ELASTICITY OF PLYWOOD IN COMPRESSION¹

By

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This report presents a method developed at the Forest Products Laboratory for calculating the compressive strength and moduli of elasticity of plywood. This method is based on tests which to date have been limited to (1) plywood in which the grain of the alternate plies is at right angles, (2) loading conditions in which the compressive stress is either parallel or perpendicular to the direction of the grain of the face plies, and (3) plywood in which all plies are of the same species. The tests are being continued to amplify the data and to cover additional plywood constructions. The methods indicated are, hence, subject to modification as additional data become available. The formulas and discussion relate to members or specimens of such size and supporting conditions that the compressive stress is the controlling factor; accordingly, the data here presented are not applicable to plywood columns or plates where buckling is the controlling factor.

The following formulas, which mathematically are only approximate, have been found by test to be satisfactory for computing the compressive strength and modulus of elasticity of plywood, when the stress is parallel or perpendicular to the direction of the face grain and the grain of alternate plies is at right angles:

$$S = S_L \frac{A_L}{A} \left[1 + \left(\frac{E_T}{E_L} \right) \left(\frac{A - A_L}{A_L} \right) \right] = S_L \frac{A_L}{A} (1 + r_T k) \quad (1)$$

$$E_a = E_L \frac{A_L}{A} \left[1 + \left(\frac{E_T}{E_L} \right) \left(\frac{A - A_L}{A_L} \right) \right] = E_L \frac{A_L}{A} (1 + r_T k) \quad (2)$$

where:

A, is the total area.

A_L, is the area of the plies whose grain is parallel to the direction of the applied forces.

¹This is one of a series of progress reports prepared by the Forest Products Laboratory relating to the use of wood in aircraft. Results here reported are preliminary and may be revised as additional data become available.

A_T , is the area of the plies whose grain is perpendicular to the direction of the applied forces ($A_T = A - A_L$).

$$k = \frac{A - A_L}{A_L} = \frac{A_T}{A_L}$$

S , is the average unit stress over the total area (either the unit maximum crushing stress or the unit fiber stress at proportional limit, depending on whether S_L is the maximum crushing stress or proportional limit value).

S_L , is the unit compressive stress parallel to the grain (longitudinal).

E_a , is the modulus of elasticity of plywood in compression.

E_T , is the modulus of elasticity of wood in compression perpendicular to grain (tangential).

E_L , is the modulus of elasticity of wood in compression parallel to grain (longitudinal).

$$r_T = \frac{E_T}{E_L}$$

The value of the ratios $\frac{E_T}{E_L} = r_T$ and $\frac{E_R}{E_L} = r_R$, where E_R is the modulus of elasticity of wood in compression perpendicular to the grain (radial), are available for a few species, although the data are incomplete in that little is known about the variation of these ratios with changes in specific gravity and moisture content. These data are reported in "Elastic Properties of Wood," Forest Products Laboratory Report 1528 and supplements thereto. For species on which no data are available, the use of average values of $r_T = 0.05$ and $r_R = 0.10$ is suggested, which will give a good approximation of results.

It may be noted that the strength and moduli of elasticity of plywood are largely dependent on the relative area of the plywood whose grain is parallel to the direction of test. Since r_T is small, the value of the term, $r_T k$, is small compared to unity so that a good approximation of the property desired can be obtained even if this term is omitted.

The formulas presented herein have been found satisfactory for plywood made from rotary-cut veneer. No tests on plywood from quarter sliced veneer have thus far been made. Presumably the formulas will prove applicable to this latter case if r_R is substituted for r_T in formulas (1) and (2) and $k = \frac{A_R}{A_L}$.

One of the common plywood constructions met in practice is that in which all plies are not of the same species. The strength and moduli of elasticity of this type of plywood cannot be calculated by means of equations 1 and 2, although the basic formulas are in general believed to be applicable. While subsequent tests need to be made to check this theory, it is believed that the following formulas can be used for calculating the compressive strength and moduli of elasticity of multi-species plywood:

$$S = \frac{S_{L_1} \left(A_{L_1} + \frac{E_{T_1}}{E_{L_1}} A_{T_1} \right) + S_{L_2} \left(A_{L_2} + \frac{E_{T_2}}{E_{L_2}} A_{T_2} \right) + \dots}{A}$$

$$= \frac{S_{L_1} \left(A_{L_1} + r_{T_1} A_{T_1} \right) + S_{L_2} \left(A_{L_2} + r_{T_2} A_{T_2} \right) + \dots}{A} \quad (3)$$

$$E_a = \frac{E_{L_1} \left(A_{L_1} + \frac{E_{T_1}}{E_{L_1}} A_{T_1} \right) + E_{L_2} \left(A_{L_2} + \frac{E_{T_2}}{E_{L_2}} A_{T_2} \right) + \dots}{A}$$

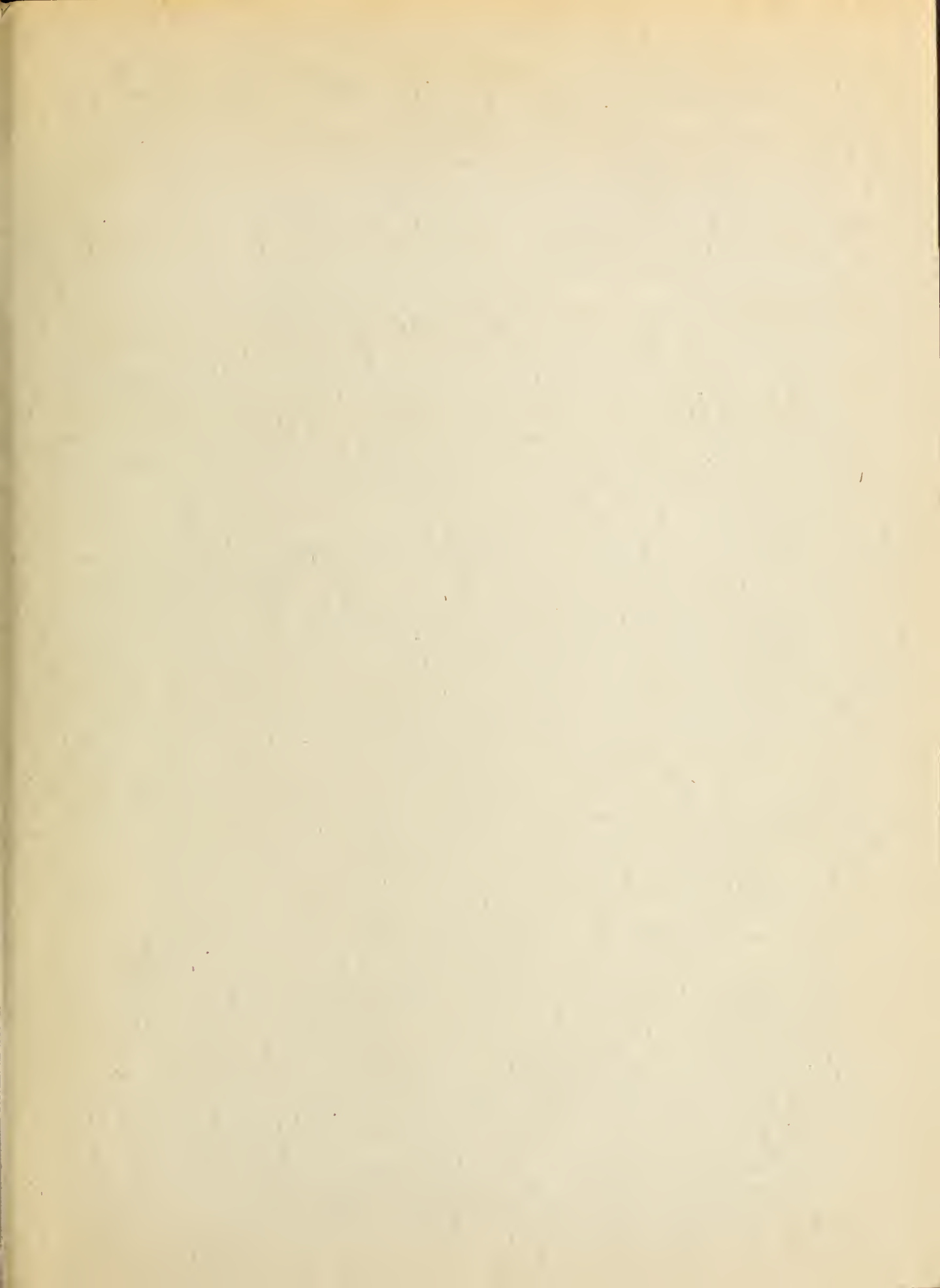
$$= \frac{E_{L_1} \left(A_{L_1} + r_{T_1} A_{T_1} \right) + E_{L_2} \left(A_{L_2} + r_{T_2} A_{T_2} \right) + \dots}{A} \quad (4)$$

where the terms have the meanings previously indicated and the subscripts 1, 2, etc. refer to the different species.

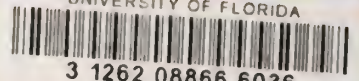
The unit stress and moduli of elasticity values to be used in the formulas can be obtained from previously published data. To give a more correct result, these values should be adjusted to the specific gravity of the plywood and to the expected moisture content when in service. U. S. Department of Agriculture Technical Bulletin No. 479, "Strength and Related Properties of Woods Grown in the United States," will probably furnish most of the desired values for obtaining maximum stresses. While no values for the moduli of elasticity in compression will be found therein, they may be obtained by increasing the bending moduli values by 10 percent to correct for shear deformation. Basic stress values and methods for determining working or design stresses for structural timbers may be obtained from U. S. Department of Agriculture Miscellaneous Publication No. 185, "Guide to the Grading of Structural Timbers and the Determination of Working Stresses." ANC Bulletin 18, "Design of Wood Aircraft Structures," provides information for a number of aircraft woods. The appropriate values to be substituted in the formulas will depend upon the information desired or upon the manner in which the plywood is to be used.

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